DENISON UNIVERSITY BULLETIN

Volume XXXII, No. 10

JOURNAL

OF THE

SCIENTIFIC LABORATORIES

Volume XXVII **Article 1** **Pages 1 to 46**

EDITED BY

W. C. EBAUGH

Permanent Secretary Denison Scientific Association

1. The Geomorphic Development of Central Ohio (Part I). By Henry S. Sharp 1

GRANVILLE, OHIO

JUNE, 1932

The University Bulletin is issued bi-monthly and is entered at the Post Office in Granville, Ohio, as mail matter of the Second Class

JOURNAL
OF THE
SCIENTIFIC LABORATORIES
OF
DENISON UNIVERSITY

The entire file of volumes 1 to 13 was destroyed by fire; no publications issued prior to 1907 are now available. Volumes 14 to date may be obtained from the editor at $2.00 per volume, with the exception of volume 15, the price of which is $1.00. Separate parts, as listed below, may be purchased at the prices indicated.

VOLUME 14

Articles 1-5, pp. 1-60; Nov., 1908 ..... $0.50

Pre-Wisconsin drift in the Finger Lake Region of New York; F. Carney. 16 pp., 4 figs.
An esker group south of Dayton, Ohio; Earl R. Scheffel. 15 pp., 6 figs.
Wave-cut terraces in Keuka Valley, older than the recession stage of Wisconsin ice; F. Carney. 12 pp., 3 figs.
A form of outwash drift; F. Carney. 8 pp., 1 fig.
State geological surveys and practical geography; F. Carney. 6 pp.

Articles 6-10, pp. 61-188; April, 1909 ..... $1.00

Fossils from the Silurian formations of Tennessee, Indiana, and Kentucky; Aug. F. Foerste. 56 pp., 4 plates.
Studies on Babbitt and other alloys; 10 pp. J. A. Baker.
A stratigraphical study of Mary Ann Township, Licking County, O. 28 pp., 15 figs. F. Carney.
Significance of drainage changes near Granville, Ohio; Earl R. Scheffel. 17 pp., 2 figs.
Age of the Licking Narrows; K. F. Mather. 13 pp., 5 figs.

Articles 11-16, pp. 189-287; June, 1909 ..... $0.75

A spectrometer for electromagnetic radiation; A. D. Cole. 10 pp., 6 figs.
The development of the idea of glacial erosion in America; F. Carney. 10 pp.
Preliminary notes on Cincinnatian fossils; Aug. F. Foerste. 20 pp., 1 plate.
Notes on Spondylomorum Quaternarium Ehrenb; M. E. Stickney. 5 pp., 1 plate.
The reaction to tactile stimuli and the development of the swimming movement in embryos of Diemyctylus torsus Eschscholtz; G. E. Coghill. 21 pp., 6 figs.
The raised beaches of the Berea, Cleveland, and Euclid sheets, Ohio. F. Carney. 25 pp., 5 figs.

Articles 17-18, pp. 289-442; November, 1909 ..... $1.00

Preliminary notes on Cincinnatian and Lexington fossils; Aug. F. Foerste. 45 pp., 5 plates.
The Pleistocene geology of the Moravia Quadrangle, New York; Frank Carney. 105 pp., 27 figs.

VOLUME 15

Article 1, pp. 1-100; March, 1910 ..... $1.00

Bulletin in commemoration of Clarence Luther Herrick.

VOLUME 16

Articles 1-3, pp. 1-120; June, 1910 ..... $1.10

The metamorphism of glacial deposits; F. Carney. 14 pp., 7 figs.
Preliminary notes on Cincinnatian and Lexington fossils of Ohio, Indiana, Kentucky, and Tennessee; Aug. F. Foerste. 81 pp., 5 figs., 7 plates.
The abandoned shorelines of the Oberlin Quadrangle, Ohio; Frank Carney. 16 pp., 5 figs.

Articles 4-7, pp. 119-232; Dec., 1910 ..... $0.75

Standardization of well water in the vicinity of Granville, Ohio; Lily Bell Sefton. 5 pp.
Chapters on the geography of Ohio; F. Carney.
Transportation; 11 pp.
Economic mineral products; 47 pp.
Glaciation in Ohio; 48 pp.

Articles 8-12, pp. 233-346; April, 1911 ..... $0.75

The abandoned shorelines of the Vermilion Quadrangle, Ohio; F. Carney. 12 pp., 2 figs.
Thermo-electric couples; A. W. Davidson. 21 pp., 16 figs.
The Mercer limestone and its associated rocks in the Newark-Zanesville region; Clara G. Mark. 47 pp., 2 plates, 5 figs.
A study of the supposed hybrid of the Black and Shingleoaks; Earl H. Foote. 18 pp., 4 plates.
A case of pre-glacial stream diversion near St. Louisville, Ohio; Howard Clark. 8 pp., 4 figs.

Articles 13-17, pp. 347-423; July, 1911 ..... $0.65

The Swasey Observatory, Denison University; Herbert G. Wilson. 5 pp., 4 figs.
The contribution of Astronomy to general culture; Edwin B. Frost. 12 pp.
The geological development of Ohio; F. Carney. 15 pp.
The relief features of Ohio; F. Carney. 13 pp., 1 fig.
Geographic conditions in the early history of the Ohio country; F. Carney. 20 pp.

X

THE GEOMORPHIC DEVELOPMENT OF CENTRAL OHIO

PART I

HENRY S. SHARP

Received March 18, 1932; published June 30, 1932

TABLE OF CONTENTS

Introduction 1
Acknowledgments 3
Location of Area 3
Areal Geography 5
Geologic Structure of the Area 8
Outline of the Geomorphic History of Central Ohio 9
The Preglacial History 10
  Pre-Harrisburg Development 10
  The Harrisburg Cycle 15
  The Somerville Cycle 17
  The Post-Somerville Cycle 26
  A Geomorphic Comparison of Central Ohio and Central Kentucky 27
  Structural Effects in Central Ohio 31
Geomorphic Results of Glaciation 34
  Influences on Relief 34
  Glacial Modifications of Drainage 42
Bibliography 44

INTRODUCTION

Reference to geologic bibliographies will show a long list of papers discussing the surface features of Ohio, and to many it may seem that an additional paper on the same subject can accomplish no useful purpose. A short study of this rather imposing bibliography will show, however, that an overwhelming number of these papers are devoted to landforms of considerable local interest but often of little significance to the regional geomorphic history of Ohio. No matter how interesting such problems may be in themselves, an understanding of the history of local modifications of drainage and of the origin of minor glacial features should gain its chief importance when used in conjunction with

many other such examples to indicate the major steps in the development of a region. Such regional discussions of Ohio geomorphology as have appeared have unfortunately been confined either to the limits of one county or of one quadrangle, areas in general too small to give a comprehensive picture of the genesis of the major topographic features of the state. In this paper the features of minor importance will be discussed as episodes in the major history of an area in central Ohio selected to illustrate the two most important topographic divisions within the state. These divisions furthermore extend into neighboring states so that the chief steps in the genetic history proposed here should be regional in application.

The present paper is based upon field observations made largely during the summer of 1931 and upon a study of the extensive list of articles in which the surface features of the area have been discussed. Central Ohio has been intensively studied in the field, and new observations from that source are few. The chief aim is to present a genetic history of landform evolution in which the origin of the major features is emphasized, and the smaller forms are shown in relationship to the larger. No claim to originality is made, but many of the interpretations in the following pages are believed to be new. More than anything else it is hoped that this paper may be an orderly summary of the geomorphology of central Ohio.

To those unacquainted with Ohio, the state would seem to offer few inducements to geomorphic studies. No igneous or metamorphic rocks outcrop, and the entire area is underlain by Paleozoic sediments of extremely low regional dip. Such structural simplicity is likely to be reflected by a lack of variety in surface expression, but in Ohio occur three regions which because of their distinctive topography have been designated separate physiographic provinces by the Association of American Geographers (*9*). Furthermore, two of these provinces are each represented by two sections, so that the important physiographic divisions within the state number five. The most marked of these divisions are the great Central Lowland and the Appalachian Plateau provinces, whose characteristic differences in elevation

and topography are very evident even to the casual traveler passing east or west across the state. The difficulty of determining the origin of these two areas of structural similarity is increased rather than decreased by the horizontal attitude of the rocks, for the possibilities of structural control as opposed to peneplanation must be considered, a difficult problem which is avoided in areas where widespread erosional surfaces bevel the structure sharply. The relationship between the major erosional surfaces of the two provinces is, therefore, an important problem of more than local interest. Very much has likewise been written upon glacial modification of drainage in Ohio, but many aspects of the problem are still baffling, and the final solution may not appear until geophysical methods are used in tracing the unknown courses of valleys still deeply buried by the drift. Here again the difficulties of solution are increased by the horizontal structure, since it is almost impossible to suggest the probable preglacial courses of insequent streams where drainage has developed without structural control. The absence of structural diversity has doubtless resulted in a much smaller variety of features of interest to the geomorphologist, but as later pages will indicate the correct understanding of those features which he must explain has not always been made easier by this simplicity.

ACKNOWLEDGMENTS

To his colleague, Professor Frank J. Wright, the author wishes to express appreciation for numerous discussions both in office and field concerning the geomorphology of the western escarpment region of the Appalachian Plateau. Professor Wright kindly read that part of the manuscript covering the preglacial history and offered welcome suggestions and criticisms throughout its preparation.

The author is conscious of many defects in what is to follow and is responsible for the opinions expressed therein.

LOCATION OF AREA

This paper discusses a rectangular area of about 3500 square miles within which is the geographic center of Ohio. It includes

fifteen quadrangles of the United States Geological Survey arranged in a block three quadrangles wide from north to south and

FIG. 1. THE RECTANGULAR AREA IS THAT DISCUSSED IN THIS PAPER
(Courtesy of A. K. Lobeck)

five quadrangles long from east to west; the names of these quadrangles follow: top tier from west to east, Delaware, Marengo,

Fredericktown, Gambier, Brinkhaven; middle tier, Dublin, Westerville, Granville, Newark, Frazeysburg; bottom tier, West Columbus, East Columbus, Thurston, Thornville, Zanesville. The important cities of Columbus, Delaware, Newark, Mt. Vernon, and Zanesville (Fig. 1), lie within the area which includes all of the following counties: Delaware, Franklin, and Licking; and parts of the counties of Pickaway, Fairfield, Perry, Morgan, Muskingum, Coshocton, Holmes, Knox, Morrow, Marion, Union, and Madison.

AREAL GEOGRAPHY

The area is naturally divided into two sections of very different topography by an inconspicuous westward-facing escarpment which extends from north to south through the eastern edges of the Marengo, Westerville, and East Columbus quadrangles. This gentle slope which is seldom less than six miles in length rarely shows a grade of 100 feet per mile and probably averages nearer 50 feet. The observer stationed upon it finds the slope incredibly low for an escarpment, but, to one viewing it from the west or from its crest looking westward, it becomes evident as an important feature some 300 feet in height. The Appalachian Plateau province lies to the east of this escarpment, to the west, the great Central Lowland.

The maximum relief within that part of the area belonging to the Appalachian Plateau is 750 feet, the highest elevations, about 1420 feet, occurring on the Fredericktown sheet, the lowest, 670 feet, on the Zanesville quadrangle where the Muskingum River leaves the area. These figures are extreme, for the usual relief is between 200 and 300 feet. The Plateau section can best be pictured as an extremely dissected upland in which the tops of the well rounded hills rise in general to accordant elevations of 1000 to 1300 feet. The depth and amount of dissection diminishes westward, and a divide zone several miles wide just east of the bounding escarpment is flat and poorly drained. Most of the plateau is well drained by an intricately branching system of streams which at length deliver their waters eastward into the Muskingum River. The Muskingum flows southward along the

eastward boundary of the area but enters it only for a short distance at Dresden and north and south of Zanesville where it turns southeastward to enter the Ohio at Marietta. The important eastward flowing streams which drain the plateau area into the Muskingum are from north to south: the Kokosing and Mohican Rivers uniting to form the Walhonding River; Wakatomika Creek entering the Muskingum at Dresden; the South, Raccoon, and North Forks of the Licking uniting at Newark to form the Licking, which flows southeastward to the Muskingum at Zanesville; and Jonathan Creek entering Moxahala Creek a few miles southwest of Zanesville where the latter enters the Muskingum. The width of the valleys occupied by these streams often vary greatly within short distances, and broad flood-plains may be abandoned abruptly for a rock-walled gorge.

The characteristic irregularity of the Plateau is relieved by a number of broad valleys with terraced bottoms, which in many cases are occupied by relatively insignificant streams. The most striking of these valleys converge upon Newark from the southwest, west, north, and northeast. The latter extending from Dresden southeast to Newark, a distance of 24 miles, averages a mile in width, and for more than one-third of its length is occupied by no longitudinal stream worthy of mention. From well records this valley is known to be filled in places with over 300 feet of stratified gravel, sand, and clay, while the steep valley walls rise with notable abruptness 200 or 300 feet above the generally flat surface of the fill. Such stratified deposits from 50 to 300 feet in thickness are found in very many of these broad valleys.

The escarpment between the Appalachian Plateau and the Central Lowland is notably straight and in this area is interrupted only once. This break in the otherwise continuously westward-facing slope is twelve miles southeast of Columbus and from north to south is four miles wide. On entering this broad gap one finds himself in a flat bottomed valley maintaining its width for nearly 20 miles and leading eastward to Buckeye Lake thence northeastward to Newark, where its width is still over two miles. Here it divides into three valleys opening toward Newark, as

mentioned in the previous paragraph, from the west, north, and northeast. The lowland forming the floor of this great valley has the topography of that part of the Central Lowland around Columbus. Its flat surface merges imperceptibly with the Central Lowland at the gap and is 200 or 300 feet below the hilltops of the immediately adjacent upland. The break in the escarpment hence leads into a considerable area of lowland which is to be regarded as a large eastward extension of the Central Lowland into the Appalachian Plateau. North of this break others were probably present, but they have been entirely hidden by drift.

In elevation, topography, and drainage that part of the area lying within the Central Lowland, and which for convenience will be called the Columbus Lowland, differs importantly from the Appalachian Plateau. In the northwestern part of the area on the Delaware and Marengo quadrangles the general level of interstream divides is 950 to 980 feet, but southeast of Columbus on the East Columbus Quadrangle most of the surface lies between 700 and 750 feet, so that the surface of the Columbus Lowland slopes imperceptibly southward about seven feet per mile. The Lowland is a monotonous plain of little dissection, and large areas as "flat as a floor" are common. In accordance with the slope the major streams flow southward in courses almost parallel for long distances but gradually converge upon the Scioto into which all finally flow. The Scioto, which is the master stream, at Chillicothe flows from the Lowland into the Plateau and at Portsmouth enters the Ohio River. From west to east Darby Creek, Scioto River, Olentangy River, Alum Creek, Big Walnut Creek, and Little Walnut Creek are the important streams draining the Columbus Lowland.

The valleys of these streams are not comparable in width and depth to those found in the Plateau. North of Columbus they rarely exceed one half mile in width, and for the most part the valley bottoms are narrow and almost entirely occupied by the stream. No broad valleys without streams occur. In depth the valleys may reach 150 feet below the general lowland surface, the average depth, however, is nearer 100 feet, and south of

Columbus the Scioto has a broad and shallow valley. Although from the divides their presence might scarcely be suspected, the valleys of these streams and their tributaries provide the only important departure from the almost featureless surface of the Lowland. In spite of its generally flat surface and its location within the glacial boundary the Columbus Lowland lacks the numerous swamps and lakes such as characterize many glaciated areas. Contrasted with the beautifully developed dendritic drainage pattern of the Plateau the Lowland drainage is poorly developed dendritic with a strong tendency to parallelism because of the alignment of the major streams.

Except for the alluvium of the stream bottoms the soil is largely drift so distributed that rock outcrops are extremely rare and almost lacking except where caused by stream erosion. The drift cover the Lowland has thus largely concealed the preglacial topography in marked contrast to the glaciated plateau where the preglacial relief has been decreased but not hidden by the presence of very thick deposits in the valleys and of very thin veneers on the hilltops.

GEOLOGIC STRUCTURE OF THE AREA

For the purposes of the geomorphologist little need be said concerning the structural geology of Central Ohio. Only sedimentary rocks occur; the area is situated on the eastern limb of the Cincinnati Arch, hence all the formations dip eastward. The dip averages between 20 and 30 feet per mile and is of course imperceptible in a single outcrop. Too low to have an important effect on the alignment of valleys and ridges it does cause successive formations to appear at the surface in bands of outcrops extending from north to south. These outcrops from west to east across the area rise in age from Silurian to Pennsylvanian; each formation outcrops over a broad area because of the extremely low dip, and the area occupied by each formation is essentially one of homogeneous resistance to erosion. Areas of equal resistance are thus very widespread and, because adjoining formations are often quite similar in resistance, may extend over a still greater width of country than that underlain by any one formation. In central Ohio important differences in rock resist-

ance due to the slight departure from horizontality of dip number but one. The Lowland comprising the western one-third of the area is underlain by the Monroe, Columbus, and Delaware limestones, the Ohio and Olentangy shales, five formations which act as a unit toward erosive agencies and are less resistant than the rocks underlying the Plateau. The escarpment marks a geologic as well as a topographic boundary, for its base closely parallels the contact between the Middle Paleozoic formations mentioned above and the Carboniferous rocks. The latter are predominately arenaceous shales, sandstones, and occasional conglomerates with geomorphically unimportant coals and limestones. The shales and sandstones act as one toward erosion, and their greater resistance is indicated by the greater altitude of the eastern two-thirds or Plateau section of the area.

Faulting, jointing, and minor folding are present to a small degree but have no effect upon the topography, and the geomorphologist is safe in concluding that the only structural effect of importance in central Ohio is that of the regional dip described above in bringing rocks of two different resistances within the influence of erosion.

OUTLINE OF THE GEOMORPHIC HISTORY OF CENTRAL OHIO

Only in so far as it directly determines the surface topography is the geology of an area necessary to its geomorphic history. Thus many formations, unconformities, and features of great significance in the geologic history of central Ohio may be of no importance whatsoever to the history of its surface development and therefore should be omitted from a geomorphic paper. Those steps which are indicated directly by the present topography of central Ohio are listed below in outline form. In succeeding paragraphs each step will be discussed in appropriate detail.

1. In pre-Harrisburg time a great series of Paleozoic sediments was deposited, then uplifted, and tilted slightly toward the east. (Appalachian Revolution.)

2. Long continued erosion reduced the uplifted area nearly to sealevel producing a widespread peneplane. (The Harrisburg Cycle.)

3. This peneplane was uplifted resulting in the erosion to near

baselevel of the areas underlain by non-resistant rock and the dissection to maturity of areas of more resistant rock. (The Somerville Cycle.)

4. Another uplift caused erosion of the peneplaned weak rock areas and the still deeper dissection of the resistant rock areas. (Post-Somerville Cycle.)

5. Glaciation interrupted the above cycle. At least two advances of the ice occurred resulting in great alterations of the preglacial topography and important modifications of drainage.

6. With the withdrawal of the ice present day erosion and weathering started and has been chiefly marked by the terracing of valley deposits.

THE PREGLACIAL HISTORY

Pre-Harrisburg

1. During the Paleozoic Era Ohio was predominantly an area of sedimentation; at its close the deposition of the materials forming the constructional block from which erosion was to carve the present topography had been completed. None of the ancient erosional surfaces which are now seen as unconformities have any effect upon the present surface forms. They may, therefore, be disregarded, for in spite of these interruptions in deposition the Paleozoic formations of central Ohio have practically the same attitudes, and the geomorphologist may consider them a structural unit. The total thickness of the exposed beds is said to be about 5500 feet (*6*); in the region under discussion the older formations are limestones and shales, the younger, sandstones and sandy shales almost exclusively.

The diastrophism which in eastern Pennsylvania and West Virginia formed the Folded Appalachians likewise ended the era here. Far from the deforming stress the disturbance was mild and apparently did little more than to raise the entire region into the domain of erosion. At this time the Cincinnati Arch and the Pittsburg syncline, great flexures of earlier beginning, were accentuated, and the formations of Central Ohio being situated on the eastern limb of the Arch were tilted into an eastward regional dip of 20 to 30 feet per mile.

Speculation concerning the altitude of the Cincinnati Arch at the beginning of Mesozoic time may be unprofitable, but the ancient topography of Ohio is nevertheless a subject of interest. Was the surface of the state ever much higher than now? The many factors which make any attempt at an answer subject to broad error will be recognized by the reader and need not be enumerated here. The top of the Ohio shale, which is taken as a guide horizon in the attempt to reconstruct the former surface, east of Columbus is 800 feet above sealevel. In the same latitude the axis of the Cincinnati Arch is about 70 miles to the west. Assuming a dip of 20 feet per mile, a figure low enough to allow for some flattening as well as thinning of beds on the crest of the Arch, the restored top of the Ohio shale along the axial line would be 2200 feet above present sealevel. If the formation did not extend across the Arch, the crest must have been somewhat higher than the figure given. The occurrence of a large outlier of shale in Logan County only a few miles east of the axial zone of the Arch indicates that it probably extended almost or quite across the crest. If the axial area were not covered, it still must have been extremely narrow and therefore only slightly higher than the bordering Ohio shale and the elevation of 2200 feet above sealevel.

During Late Paleozoic time the axial area of the Cincinnati Arch had become for the most part a landmass subjected to erosion, and it is unlikely that much material was deposited there after the middle of the era. If the Ohio shale did extent across the Arch, a considerable thickness may have been eroded by the end of the Paleozoic, and the figure of 2200 feet above present sealevel obtained by extending the dip of the top of the formation would be too high. If the restoration is remotely correct, it still does not mean that the surface of the Arch stood at an elevation of 2200 feet above sealevel at the beginning of the Mesozoic, for the presence of the Harrisburg peneplane in the Plateau at an elevation of 1000 to 1300 feet above sealevel indicates that the entire region has been elevated by nearly that amount since the Mesozoic. If this is true, the restored elevation of 2200 feet would have to be decreased by the amount the Harrisburg has

been raised leaving the initial height of the Cincinnati Arch about 1000 feet above sealevel. Actually it may have been less, since one or two periods of baseleveling of which there is no trace may have intervened before the peneplanation mentioned above. The author realizes the danger of these figures but believes nevertheless that they do point to the conclusion that within the period of geologic record Ohio has never been higher or as high as its present highest elevation of 1500 feet in Logan County.

It appears certain that the area of the Cincinnati Arch was higher than that of the Pittsburg syncline at the end of the Paleozoic, and that the difference in elevation was consequent, that is, due to diastrophism and not to erosion. Ohio may then have had little minor relief but two major topographic features, an elongated elevated region and a similar depressed region, which extended across the state in a northeasterly direction along the axial trend of the present Arch and syncline. If the geographic conditions were thus at the beginning of the Mesozoic, a longitudinal consequent stream probably occupied the elongated basin formed by the Pittsburg syncline. Tributary to this stream many transverse consequents would flow down the southeastern flank of the Cincinnati Arch. Many other consequents flowing westward from the newly uplifted Appalachians would also enter this longitudinal major stream. Theoretically at least such was the drainage and geography of the Early Mesozoic. Today many Ohio streams occupy courses somewhat similar to those inferred above, but it is probably erroneous to suppose that many of them are resequents occupying ancestral positions at lower elevations.

Did these early streams succeed in baseleveling Ohio during the Mesozoic, or was that region once more brought under the régime of sedimentation? Not the slightest evidence of the former presence of Mesozoic sediments exists within Ohio, and their nearest outcrop in the Mississippi Embayment of the Coastal Plain is over 250 miles away. Even with the once greater extent of the Atlantic Coastal Plain deposits over the peneplaned Appalachians (*13*) in mind, it seems unlikely that the Mesozoic sediments of the Mississippi Valley were ever to be found within the boundaries of Ohio. If not, this region suffered

erosion during the entire Mesozoic, although no erosional surfaces of that era are now recognized in Ohio.

In the absence both of deposits and of land surfaces belonging to the Mesozoic, ideas concerning the history of that time must be gained from neighboring areas and from inference concerning the probable sequence of events. In many still valuable accounts the accordant hilltops of the Appalachian Plateau were stated to be remnants of a Cretaceous peneplane (*26, 6*). It is now generally recognized, however, that the so-called Cretaceous peneplane of the Appalachians, the Schooley peneplane, does not extend into Ohio, but that the oldest peneplane within the state is probably that one called the Harrisburg from its excellent development around Harrisburg, Pennsylvania (*1, 27*).[1] Were the summit peneplane of the plateau the Schooley, there would still be no Mesozoic land surface in Ohio, since the Schooley is no longer to be regarded as a Cretaceous surface. One noting the very resistant character of the rock preserving the Schooley in the Appalachian Mountains and the New England province might well have argued against its survival, if ever present, on the less resistant rocks of the Ohio plateau.

Consideration of the great length of the Mesozoic Era and of the then comparatively slight elevation of Ohio leads to the conclusion that the region must have been baseleveled one or more times during the era. In the New England, Newer Appalachian, and Piedmont Provinces at least three well developed peneplanes (*21*) were formed after the close of the Paleozoic and before the formation of the Harrisburg. These were eroded on more resistant rock than is common in Ohio and in areas of supposedly considerable elevation. It seems probable then that such a low-lying region of non-resistant rock as central Ohio must have been peneplaned at least once in the same length of time. Presumably this peneplane, if restored, would be situated only a few hundred feet above the Harrisburg, but in Ohio all evidences of it have been destroyed.

[1] So far as known to the writer all geomorphic papers of the last fifteen years have assigned the highest peneplane to the "Tertiary" or Harrisburg Cycle. Space prevents their mention in a footnote reference.

During the Mesozoic baseleveling or baselevelings the Cincinnati Arch must have been breached, and the agents of denudation must then have discovered the differences in resistance between the Mid-Paleozoic limestones and shales and the Late Paleozoic arenaceous sediments. The prototype of the present escarpment between the Plateau and Lowland then came into existence facing westward as now but, because developed at a higher elevation on the eastward dipping beds, situated an unknown number of miles (70 or less) west of the present escarpment. Along the crest of the breached anticline a longitudinal subsequent stream would normally develop growing in importance as the obsequents flowing down the scarp face encroached upon the drainage areas of the older transverse consequents flowing eastward into the Pittsburg basin. With the continuation of this process of encroachment and capture, the old longitudinal consequent of the basin lost most of its tributaries, and may itself have been turned into a tributary of the subsequent following the axial line of the Arch. When this occurred the escarpment had retreated many miles to the east growing lower with each mile of retreat until it and any other cuesta-like elevations which may have developed upon the gently dipping strata became utterly inconspicuous. Now the streams were free to wander widely from their old courses, which had been directed to a certain extent by structural as well as slope control.

Though their paths must forever remain unknown it seems likely that the major drainage lines of the region already led toward the Gulf of Mexico, which during part of the Mesozoic was less than 500 miles from Ohio and formed the nearest baselevel. No figures are available to show the amount of seaward slope of undisturbed peneplanes, but at the end of the last Pre-Harrisburg Cycle Ohio must have been a region of slight relief standing relatively low, possibly only one or two hundred feet above sealevel. Although incapable of proof it is distinctly probable that the Ohio region was reduced to this condition at least twice before the uplift which initiated the Harrisburg Cycle and that two peneplanes were formed corresponding to the cycles which in the Appalachians have been called the Fall Zone and

the Schooley. Present knowledge (*14*) indicates the Schooley peneplane to be no older than Tertiary, and it is evident that the oldest surface in Ohio can in no case be older than that.

The Harrisburg Cycle

2. The Harrisburg Cycle is the first of which there is any actual record in Ohio, for the peneplane developed at that time remains in the accordant hilltops of the Plateau. It is the most ancient erosional surface within the state, and there is no evidence to prove that it was not the first to be completed after the Appalachian Revolution. It seems more probable that one or more periods of baseleveling intervened, and it was the last of these, possibly the Schooley Cycle, that terminated in the uplift initiating the Harrisburg Cycle. The exact amount of uplift can never be determined; if the Harrisburg were the first cycle after the Paleozoic, it might be placed around 1200 or 1300 feet allowing for an elevation of the Harrisburg at completion of 100 or 200 feet and adding this amount to the difference in elevation between the restored Cincinnati Arch, 2200 feet, and the present elevation of the peneplane, possibly averaging 1100 feet in Central Ohio. If one or more cycles of erosion occurred before the Harrisburg, this amount would be greatly reduced, since some of the total uplift estimated above would have taken place at the beginning of each cycle leaving only a few hundred feet of elevation to begin Harrisburg erosion.

One may enthuse over the excellent preservation of the Harrisburg peneplane in Ohio. From almost any exposed hilltop such views as shown in Plates I and II are presented to the eye, and the skyline is so even that frequently throughout a sweep of 360 degrees it appears as level as a line could be drawn. Elevations, which in the field may be recognized as monadnocks are rare, and when one section of the skyline does seem to stand higher than the rest, it merges so imperceptibly with the lower that generally no line of demarcation can be drawn. Such higher elevations are believed similar to monadnocks in origin, but in this area are best pictured as somewhat less reduced parts of the peneplane. These higher parts on the Granville Quadrangle attain 1360 feet

in elevation, on the Fredericktown, over 1400 feet, on the Newark and Thornville Quadrangles over 1250, over 1300 feet on the Gambier Quadrangle, while on the Brainkhaven Quadrangle large areas of wonderfully accordant skyline exceed 1200 feet. With the exception of Bucks, Bald, and Coffman Knobs southeast of Newark and possibly Flint Ridge shown on the Thornville Quadrangle none of these elevations stand abruptly or markedly above the surrounding peneplane and do not therefore resemble the usual conception of monadnocks.

The general elevation of the peneplane within the boundaries of the area covered by this paper ranges approximately from 1300 down to 1000 feet. The higher elevations are found toward the northwest in the Fredericktown Quadrangle, the lower in the Thornville and Zanesville Quadrangles toward the southeast; the slope is about five feet per mile toward the southeast. This slope is probably due to tilting during uplift and not to greater lowering of the surface by erosion toward the southeast. Such elevations as are enumerated in the preceding paragraph, however, are interruptions to this slope and are not to be attributed to local warping during uplift but to differences in the perfection of base-leveling caused fortuitously by the presence of more resistant rock or by location at some distance from major drainage lines. A peneplane is probably never a perfectly flat surface, but one which may undulate to a considerable degree. Most of the undulations seen rising above the surface of the Harrisburg are so small that they may be rather regarded as parts of the peneplane than monadnocks, but in any case it is apparent that at its completion the surface was one of remarkable perfection.

At that time the relief and topographic diversity of Ohio was much less than now. No marked differences in elevation between the area of the present Columbus Lowland and the Plateau existed, for the former underlain by weak limestones and shales could not be eroded perceptibly below the Plateau area of more resistant rock in a cycle where long continued erosion had reduced the entire region nearly to the same baselevel. No escarpment therefore marked the western limit of the Plateau forming rocks, but possibly 15 or 20 miles west of its present situation the contact

between the weak Devonian and the more resistant Carboniferous formations indicated the line of its future appearance.

A very large proportion of the present drainage of the Plateau became established upon the even surface of the Harrisburg peneplane. The very slight structural control of a positive nature in a region whose initial relief had long since disappeared encouraged the development of insequent streams. For the most part this drainage must have been of a rarely excelled dendritic pattern, as is indicated by study of any outline map of the Plateau section, and presumably this pattern characterized the entire state at the close of the cycle. Evidences of structural or slope control such as theoretically determined the evolution of drainage in the Pre-Cenozoic seem lacking, with three possible exceptions, in the pattern inherited by the present Plateau. Tight (*26, Plate I*) has delineated the courses of three important streams including the Teays and Newark Rivers, which flowed from the Plateau area into the Lowland area of Central Ohio; their positions make it quite probable that these were in part obsequents developed as described in the preceding section on the Pre-Cenozoic history. Although other exceptions will be mentioned, an overwhelming number of the streams whose courses have been inherited from the peneplane are better classified genetically as insequents.

The Somerville Cycle

3. The Harrisburg Cycle terminated in an uplift inaugurating the erosion of a new cycle, which may be called the Somerville. So far as known to the author this term has not previously been used in Ohio, although it seems to him justifiable, if the peneplane formed in the preceding cycle is to be called the Harrisburg from a type locality in eastern Pennsylvania. In New Jersey and Pennsylvania the Somerville peneplane is the next one below the Harrisburg and is recognized as the lowest and youngest base-leveled surface. The term was first used by Davis for the region around Somerville, New Jersey, but for a number of years has been extended into the Great Valley of Pennsylvania, where the relationship between it and the Harrisburg peneplane is beauti-

fully shown. In the northeastern states the Somerville Cycle was far too short to allow peneplanation of any but the weakest rocks, and in the Great Valley the surface is developed only on the limestones and is practically coextensive with them from the vicinity of Harrisburg northeastward into New Jersey; as indicated by Ward (*29*) the peneplanation may have been largely by solution. The erosion surface formed in this cycle is widespread geographically, although its areal extent in any one locality is usually restricted to the outcrops of weaker rocks.

Geomorphologists, as is witnessed by the valuable work of Wright (*32*) in the Southern Appalachians and of Ver Steeg (*27*) in eastern Ohio and western Pennsylvania, have not hesitated to apply the term Harrisburg to peneplanes at considerable distances from the type locality of that surface. Such extension is undoubtedly proper, and its correctness becomes quite certain, when, as in the case of the Harrisburg, the peneplanation was so universal and so widespread that the remnants can be traced across entire states. To justify the extension of the term Somerville into Central Ohio may be more difficult, but no one will deny the propriety of the term, if a peneplane equivalent to that surface is extant there.

Due to its absence throughout many intervening areas it is impossible to trace the Somerville, as has been done with the Harrisburg, from its type locality into the Ohio drainage basin. Because there is only one peneplane below the Harrisburg in eastern Pennsylvania and in central Ohio, a peneplane which in each state is restricted to rocks of similar strength, it seems probable that the surface in Ohio is the same as that in Pennsylvania and therefore quite properly to be called the Somerville. Within the area studied by the author in central Ohio neither terraces, local peneplanes, nor other evidence of any kind indicate a halt in erosion between the completion of the Harrisburg surface and the surface of the Columbus Lowland, which is correlated with the Somerville peneplane. In eastern Ohio, western Pennsylvania, and adjacent parts of West Virginia a peneplane of local extent known as the Worthington (*15*) is found. Where seen by the author in southeastern Ohio it seemed impossible to

distinguish it from a widespread structural terrace; it is the next surface below the Harrisburg, and the writer would agree with Hyde (*12*) in correlating it, the surface of the Columbus Lowland, and the Lexington peneplane of Kentucky. All these surfaces are then equivalent to the Somerville. The author does not advocate the entire abandonment of local names for peneplanes, for they will continue to serve a useful purpose in descriptions of restricted areas, or where lack of knowledge compels the selection of a noncommittal term. In general, however, the application of a term such as the Somerville taken from a classic area to a number of equivalent surfaces cannot help but unite and clarify the geomorphic histories of all the provinces in which the surface occurs.

Neither the Somerville nor the Harrisburg surfaces of Ohio may properly be called the Tertiary peneplane, since both may be of that age. When the Harrisburg was correlated with the Schooley of supposed Cretaceous age, the Somerville in Ohio was believed to be Tertiary, and the terms Cretaceous and Tertiary were long applied to the two surfaces. Since all the surfaces are now believed to be much younger, it is fortunate that these age terms for the peneplanes of the eastern United States are being replaced by locality names. The Schooley is now believed to be Tertiary in age, and it has become apparent that the Somerville may be no older than Early Pleistocene.

The present differences in elevation between adjacent remnants of the Harrisburg and Somerville may be taken as an index of the amount of uplift which initiated the Somerville Cycle. In the area covered by this paper the difference in elevation between the two surfaces near the escarpment which separates them may be placed at 300 feet. In eastern and southeastern Ohio the Somerville (Worthington) is less than 200 feet below the Harrisburg, while in west central Ohio the shale hills near Bellefontaine retain a possible Harrisburg surface at an elevation of about 1500 feet, 400 feet above the surrounding Somerville on which they are monadnocks. This indicates a progressively greater uplift toward the west culminating so far as can be determined near the axial line of the Cincinnati Arch. This warping is very slight indeed,

but it is interesting in that it seems to indicate geologically recent diastrophism along that once more mobile geanticline.

This differential tilting of about two feet per mile toward the east is insignificant but combined with the structural dip in that direction might conceivably have some effect upon the development of the rejuvenated streams now beginning to cut their way into the Harrisburg surface. The two factors ought to give streams having an eastward component in their direction of flow an advantage over those flowing westward. In time the former should lengthen their course at the expense of the latter, although the tendency might be so small as to be almost imperceptible. Careful study of the maps showing the Plateau section of the area shows the western tributaries of many north or south flowing streams on the Zanesville, Frazeysburg, Brinkhaven, Newark, Mt. Vernon, and Thornville Quadrangles to be somewhat longer than those entering the main stream from the east. Many exceptions occur, and the asymmetry is not apparent to the casual eye. Excepting those cases obviously due to glacial modification, the author would attribute most of it to structure rather than to tilting of the Harrisburg. In Jefferson County in eastern Ohio similar asymmetry of drainage has been attributed entirely to structure (*16*). It is too slight to mar noticeably the perfection of the dendritic drainage pattern, but with the possible obsequents mentioned in an earlier paragraph these resequents furnish another of the exceptions to the generally insequent drainage of the Plateau.

As soon as it felt the impulse of uplift, erosion started with renewed vigor and at once attacked the Mid-Paleozoic limestones and shales more effectively than the Carboniferous clastic sediments, and the area underlain by the former was soon lowered enough to allow sapping of the resistant formations along the line of contact. Thus the escarpment between the Lowland and the Plateau came into existence soon after the end of the Harrisburg Cycle and has continued until the present time. Because of the low eastward dip the escarpment moved in that direction about a mile for each 20 feet that it increased in height but probably never attained sufficient steepness to be called a cliff. The escarpment

is not a simple rise from the Lowland to the Plateau, but to the careful observer is revealed as a series of scarps and terraces forming steps by which the ascent is made. These terraces are of course structural in origin and mark the location of more resistant beds. Almost any road passing across the escarpment reveals these terraces, although their number may vary from place to place. Two terraces and three scarps seem to be the highest number shown in one section; there are often less, and the exact number may be uncertain because of their poor development. Their irregular occurrence would indicate that they are not everywhere developed on the same bed or formation.

The escarpment is not a line but a zone reaching a width of twelve miles in places as along the Columbus-Granville Road; the average width is probably nearer six, still too wide to show a very marked drop, since the total height of the escarpment averages only 300 feet. If most of this 300 foot change in elevation between Lowland and Plateau were not concentrated in the scarps, the break between the two provinces would be practically imperceptible. The profile of the escarpment along the Columbus-Granville Road may be described as a typical development of the characteristic step topography. Here three scarps and two intermediate terraces accomplish the rise from the Lowland at an elevation of 800 feet to the Plateau at an elevation of 1200 feet. The highest escarpment is situated just north of Pataskala and here faces southwestward; it is about two miles wide measured along the road and in that distance drops from an elevation of 1180 to 1013 feet. Two miles farther to the northwest it is unusually steep, dropping 200 feet in about one mile. From the elevation 1013, near the South Fork of the Licking at the foot of the escarpment, the road climbs imperceptibly for five miles across an area resembling the backslope of a cuesta to an elevation of about 1075 feet near the front of the higher terrace. Then in a distance of about three miles the road drops from 1075 to about 890 feet, where it crosses Blacklick Creek. This is the rather inconspicuous middle scarp, which overlooks the lower terrace, about one mile in width and of slight eastward slope. The lowest scarp, about one and a half mile in width, lowers the sur-

face from 895 to 800 feet, the elevation of the Columbus Lowland near Big Walnut Creek. Similar descriptions varying only in detail might be given for a profile drawn along any number of roads crossing the escarpment. To assign each scarp and terrace to a single rock formation is not only difficult but incorrect, since observations indicate that the same formation does not everywhere influence the topography in the same manner along the 50 odd miles of escarpment running across this area. Along the section given, however, study of the Columbus Folio seems to indicate that the Berea sandstone and resistant beds in the Cuyahoga formation cause the lower and middle scarps.

Such intermediate terraces and scarps comprising the major escarpment are expectable under the structural conditions of Central Ohio, and in a region of somewhat greater dip or of greater differences in rock resistance might have developed into a true series of westward facing cuestas. They mark a gradation in slope and topography between the Plateau and Lowland, and where the boundaries of geomorphic provinces are to be drawn with considerable detail, they may cause doubt concerning the proper location of the line at the top or the base of the composite escarpment. The author, comparing the entire escarpment to a cliff, would deem it proper to draw the boundary between Lowland and Plateau at the bottom of the escarpment, thus throwing the zone of scarps and terraces into the Plateau.

The cuesta-like form of the terraces has been mentioned and it will be noted that three streams (from highest to lowest, the South Fork of the Licking, Blacklick Creek, and Big Walnut Creek) are located at or very near the base of the three scarps, and in the case of the two situated on terraces, the South Fork and Blacklick Creek, at the rear of the backslope of the terrace. From Galena south to the National Road, Big Walnut Creek flows at the base of the westernmost scarp closely paralleling the Ohio-Bedford contact; north of Galena its tributary, Little Walnut Creek, flows through the Powell moraine, and follows the foot of the low westernmost scarp by means of its West Branch as far north as Oak Hall School in northern Kingston township. Rocky Fork, a tributary entering the Big Walnut at Gahanna, flows near the

base of the middle scarp for about seven miles and after a break of two miles its place is taken by the Blacklick and its tributaries. Blacklick Creek on the East Columbus Quadrangle flows from the Columbus-Granville Road southward for five miles along the foot of the middle scarp not far from the Berea-Sunbury contact, while the South Fork of the Licking River on the Granville Quadrangle flows from Jersey to Pataskala along the base of the highest scarp.

The courses of these streams are described because they are following depressions in large measure due to the erosion of preglacial subsequent streams. The present streams are probably consequent upon the surfaces formed by incomplete glacial filling of these preglacial subsequent valleys. They are interesting, because with the examples already cited they indicate that in addition to the plentiful insequents, drainage evolution in such a structurally flat area as Ohio has resulted in the development of resequent, obsequent, and subsequent streams.

The perfection of the Somerville peneplane in the Columbus Lowland at the completion of the cycle is determined with difficulty, because the evenly distributed cover of glacial drift rarely exposes any remnants of the peneplane to view and makes it somewhat dangerous to assume that the drift surface indicates approximately the slope and perfection of the bedrock surface hidden beneath it. Knowledge, therefore, must come chiefly from well records showing the altitude of the bedrock surface. A number of these (*22*) have been compiled and seem to show considerable range in elevation. This variation may be due to Post-Somerville erosion, which is known to have occurred, and hence does not necessarily indicate the Somerville at completion to have been a poorly baseleveled surface. Had the Harrisburg after dissection been deeply buried by drift, knowledge gained of it through well records would scarcely show the beautiful peneplane that is indicated by its accordant skyline. Such records in Central Ohio indeed would indicate a far more uneven surface than is indicated by the well records of the Columbus Quadrangle, showing the danger of assuming a poorly developed peneplane from these alone. When records from known buried channels,

which are below the Somerville, and those within, the Plateau boundary standing above the Somerville are eliminated, the elevation of bedrock in the Lowland part of the area evidently does not depart from limits conceived allowable in a peneplane. On the Delaware and Marengo Quadrangles outcrops occur at elevations around 980 feet, while south of Columbus well records show bedrock outside of buried valleys at elevations near 700 feet giving a southward slope around seven to ten feet per mile, a slope which may in part be original and in part due to tilting during later uplift. It should be noted that these figures for the bedrock surface do not vary greatly from those previously given for the drift surface in the Lowland indicating a fairly thin but even sheet of drift except over buried stream channels. Study of the elevation of bedrock found in adjacent wells shows that within short distances there are no wide variations except for buried valleys pointing again toward the perfection of the Somerville surface at its completion. A number of elevations selected at random from the northwestern part of the Richmond Quadrangle of Kentucky, where the dissected Lexington peneplane is still beautifully preserved, show as wide or wider variations in bedrock than those equally random elevations gained from well records in the Columbus Quadrangle. At completion the Somerville in Central Ohio apparently approached the perfection of its equivalent, the Lexington peneplane of Kentucky, and was a well baseleveled surface.

No monadnocks are apparent within the area covered by this paper, but about 17 miles beyond its western boundary on the East Liberty Quadrangle just east of Bellefontaine occurs a monadnock mass of exceptional prominence and interest. Its highest point is Campbell Hill, 1550 feet above sealevel, famed as the highest elevation in Ohio, while considerable areas reach elevations near 1500 feet, possibly the level of the Harrisburg peneplane. The surrounding Somerville ascends gradually to elevations around 1100 feet, whence the slope of the monadnock begins to rise sharply. The origin of this monadnock is uncertain, its higher parts are underlain by an outlier of Ohio shale, but it seems difficult to assign it to the greater resistance

of this formation, which has been eroded as completely as the limestones elsewhere. Neither in the past or present, however, has it been situated so far from major stream courses as to remain unconsumed, and it seems extremely probable that its survival is dependent in some way upon its large shale crown.

While the weak rock areas now forming the Lowland were being baseleveled, denudation met with less success against the resistant rock of the Plateau, which became more prominent in elevation as long as the selective process continued. Within the area of this study the preglacial Vernon, Alexandria, and Newark Rivers of Tight (*26*) had become established upon the Harrisburg surface and continued in their inherited courses through Somerville and into Post-Somerville time. These streams and their tributaries drained practically all of the area in the Plateau westward into the Lowland and throughout their downcutting were no doubt able to maintain courses graded with respect to the gradually decreasing level of the Lowland. As the Somerville baselevel was approached, downcutting became less and less important in proportion to lateral corrosion, and the larger streams of the Plateau began to develop broad valleys graded with respect to the Somerville surface. These were essentially extensions of the Somerville surface of the Lowland into the Plateau, and the most important, that of the Newark River, although considerably masked by later glaciation and erosion, may be seen today on the Thornville sheet as a typical Lowland area surrounded by the higher elevations of the Plateau. This extension of the Lowland is four miles wide where it passes into the hills of the Plateau between Waterloo and Pickerington on the eastern edge of the Columbus sheet. It causes a notable break or re-entrant in the escarpment and eastward soon divides, one branch going southward past Havensport to Lancaster, the other continuing east to Basil, Baltimore, and Thurston, thence northeast to Hebron, north of which the resemblance to the Lowland is less marked, although the valley can now and doubtless at completion of the Somerville cycle could be traced many miles farther toward the northeast. These outliers of the Somerville seem analogous to some of the Worthington areas.

At the completion of the Somerville, the Plateau was doubtless as maturely dissected as now with no large areas of Harrisburg surface remaining. Its total relief was probably between 300 and 400 feet, the measure of the difference in elevation between the Somerville and Harrisburg peneplanes and its appearance with the exception of certain areas strikingly like the present.

The Post-Somerville Cycle

4. The Somerville peneplanation ended in an uplift which caused important erosion before the onset of glaciation. The cycle may be the same as that which in eastern Ohio and western Pennsylvania resulted in the formation of the Parker strath, (*15*) a broad rock terrace developed along some of the larger streams. No rock terraces formed as a result of this cycle are known in Central Ohio, and little indeed is known concerning it, for glacial deposits cover the valleys developed at that time so effectively that their presence would scarcely be suspected, were it not for well records. The amount by which the Somerville was uplifted cannot be determined with certainty, for the streams never approached baselevel so nearly that the difference in elevation between their valley bottoms and the Somerville surface could be taken as a measure of the uplift. An estimate of the minimum amount may be made, however, from such well records as are helpful. On the Newark Quadrangle a well on the Hillary Farm one mile north of Hanover in the center of the old Newark valley strikes rock at an elevation of 540 feet above sealevel. This is 40 miles upstream from the point where the Newark River broke from the Plateau into the Columbus Lowland, and if the stream had a gradient of only one foot per mile the elevation of its valley bottom would be around 500 feet where it entered the Lowland. The elevation of possible Somerville remnants is here around 700 feet indicating the Post-Somerville uplift to have been at least 200 feet. Similar results are gained from depths below the Somerville of buried channels on the Columbus Quadrangle, and it becomes evident that the diastrophism ending the Somerville was comparable to the earlier diastrophisms in the geomorphic history of Ohio. That the uplift initiating this erosion was perhaps a tilting movement is shown by the southward

slope of the bedrock in the Columbus Lowland. The cycle then begun lasted long enough for the formation of large valleys, but the completion of the work of baseleveling was prevented by the arrival of the ice.

The uplift which caused the dissection of the Somerville also rejuvenated all the streams of the Plateau, and in their renewed downcutting some of these reached elevations, as deterimned by well records, of only 500 or 600 feet above sealevel. The total relief of the Plateau area then probably averaged 500 or 600 feet, twice as great as now, and probably about twice as large as the relief of the Lowland at that time. The Plateau area of central Ohio was then comparable in relief to the present topography of eastern Ohio and West Virginia around Steubenville and Wheeling, where later deposits have not concealed the valley bottoms. There are no evidences that the rejuvenated streams of the Plateau engaged in piracy or other modifying processes in this cycle; their chief activity was in deepening their valleys and in many cases apparently removing entirely any benches formed during the Somerville.

A Geomorphic Comparison of Central Ohio and Central Kentucky

At the conclusion of their preglacial development the topography of Central Ohio and of Central Kentucky must have been very similar, for the structure of the areas is alike, and their geomorphic history seems to have been identical. Glaciation is an important additional step in Ohio, affecting little of Kentucky, which therefore resembles still the Central Ohio of preglacial time. At the end of the discussion on the preglacial history and before beginning a discussion of Ohio glacial history a comparison of the two regions may be useful in emphasizing their topographic analogies and in indicating the influence of glaciation in Ohio. The comparison is chiefly between the area in Kentucky shown on the Richmond, Beattyville, London, and Manchester Quadrangles—with which the author has some personal acquaintance —and the area in Ohio covered by this paper. It should be noted that the usage of the terms Highland Rim and Cumberland Plateau is that of the Association of American Geographers.

Southwesterly across the Kentucky area runs a westward-

facing escarpment rarely more than 500 feet high; west of the escarpment is the Lexington Plain at elevations around 900 to 1000 feet, east of it the Cumberland Plateau section of the Appalachian Plateau Province whose western edge in this region may average 1400 feet in elevation. As in Central Ohio the escarpment in the main follows the Devonian-Carboniferous contact, and the author believes that the two sections separated by it correspond to the Columbus Lowland and the Plateau in that region. Beyond this there is little resemblance between the escarpments of the two regions, for as seen between Clay City and Berea the Kentucky escarpment (Plate III) is a true cliff of rather majestic aspect and of such extremely irregular front that Plain and Plateau might be described as interlocking. It further differs from its Ohio counterpart in possessing an outlying fringe of isolated knobs and mesas, features which are known to the author in only one locality in central Ohio, and that not near the escarpment. The greater steepness of the Kentucky escarpment may be due in large part to a resistant conglomerate caprock which is removed only by undercutting, whereas even the hardest rock in the gentle Ohio slope (Plate IV) erodes downward too easily to form cliffs. The mildness of the Ohio slope may be attributed also to the undoubted blanketing effect of glacial deposition. The absence of mesa-like outliers of the Plateau on the Columbus Lowland is not to be attributed to glacial erosion, for if comparable to those in Kentucky, they would have been too large to be removed by weak glaciation. Nor can it be laid to their removal by more perfect Somerville peneplanation, for base-leveling of the Lexington Plain did not remove them in Kentucky, but again it seems due to the absence of any bed strong enough to form a permanent caprock protecting masses left behind by the retreating escarpment. Where Somerville erosion reduced the Harrisburg by cutting through a markedly resistant formation such as the Black Hand sandstone, mesa-like outliers could develop in Ohio, as they have on the edge of the graded valley of Sommerville age which passes from the Thurston Quadrangle south toward Lancaster. Except that they are not located in front of the escarpment, Mt. Pleasant, the Allen Knobs, and

several other isolated hills near Lancaster are comparable to the Pilot and to Joe Lick Knob near Berea, Kentucky, and help answer the question concerning the cause of the ragged Kentucky, the regular Ohio escarpment. The Ohio escarpment would be ragged and precipitous had it retreated eastward far enough for the Black Hand to be its caprock.

On the four Kentucky Quadrangles mentioned there is a single rise from Plain to Plateau without those intermediate terraces characterizing the Central Ohio escarpment; this is not true in northeastern Kentucky, and the traveler from Lexington to Catlettsburg by way of Owingsville and Morehead will ascend one or more steps before reaching the highest level of the Plateau. These intermediate terraces are wider than those in Ohio, but with the latter are to be attributed to structural control and not to different cycles of denudation. Their location at an elevation between the Lexington Plain and the higher surface of the Plateau is like that of the Highland Rim section south of Lexington and raises a question as to how far the surfaces of the Highland Rim and the Cumberland Plateau may be controlled by structure. Furthermore, if the Cumberland Plateau[2] is of Harrisburg age in this locality, is the peneplane on the Highland Rim to be correlated with the Somerville, and the Lexington Plain called a still younger surface? If the Plateau surface were here the Schooley, the Highland Rim might be the Harrisburg, and the Lexington Plain, the Somerville, but this usual explanation is not available, for the Schooley apparently does not get far northwest of the Cumberland Mountain section.[3] Farther south in Tennessee it seems more probable that the Plateau may represent the Schooley, and the Highland Rim the Harrisburg. As a result of his brief field acquaintance with the region, the author suggests the possibility that both the surfaces of the Highland Rim and the Cumberland Plateau south and east of Lexington are to be

[2] It should be noted that only that section of the Cumberland Plateau immediately east of the Lexington Plain is meant.

[3] The section names used in this discussion are those delineated on the map, "Physical Divisions of the United States," issued in 1928 with Vol. XVIII of the Ann. Assoc. Am. Geog.

correlated with the Harrisburg, their slight difference in elevation being attributed to structural control. If this proves correct, there is no valid genetic distinction between the Rim and the Plateau in Central Kentucky.

To say that a region shows effects of slightly dipping structure does not necessarily mean that it cannot be a true peneplane, but merely that differences in the distribution of resistant and non-resistant rock have controlled to a certain extent the topography of a nearly plane (peneplane) surface. Certain features of the Cumberland Plateau of Central Kentucky indicate that it is a structurally controlled peneplaned surface. Its outer edge on the Beattyville and Richmond sheets reaches elevations of 1500 feet, 1400 is near the average, and is composed of a Pottsville conglomeratic sandstone[4] dipping eastward 20 or 30 feet per mile. The significant fact is that as one advances eastward into the Plateau the altitude becomes less, and not until points 30 or 40 miles east of the escarpment are reached does the elevation again equal that right at the Plateau edge. In the center of this broad gentle depression around Beattyville, the divides do not average much above 1200 feet, only 200 feet above the Lexington Plain, yet this area is an integral part of the Cumberland Plateau. The western edge of the Plateau is then seen to be a broad cuesta with a very gentle backslope and a steep scarp developed on the resistant conglomerate. This cuesta at the completion of the Harrisburg stood so little above that surface that the author would prefer to regard it as a structurally controlled part of the peneplane rather than a typical monadnock. Immediately south of the Lexington Plain the Highland Rim of the Interior Low Plateaus reaches summit elevations between 1250 and 1300 feet. This surface, the Highland Rim peneplane, is usually correlated with the Harrisburg "Tertiary" peneplane, and on the basis of elevation there can be no distinction between it and the surface of the adjacent Cumberland Plateau at similar elevations. Both are probably Harrisburg, and the slightly greater altitude of the outer edge of the Plateau

[4] Geol. Map of Kentucky, Kentucky Geological Surv., 1929.

is structural in origin. If this interpretation is correct, no more than two periods of baseleveling corresponding to the Harrisburg and the Somerville are required to explain the topography of Central Kentucky.

The streams of the two regions seem to differ most with respect to the depths that they are incised below the surrounding surfaces. In each state their Valley bottoms are at comparable elevations (about 500 feet) above baselevel, but because the Harrisburg and Somerville peneplanes are higher in Kentucky the depth of dissection is greater there. The Kentucky and Red Rivers shown on the Beattyville Quadrangle flow from the Plateau into the Lexington Plain in obsequent courses comparable to those of the former Vernon and Newark Rivers of Ohio. Their valley bottoms are about 900 feet below the Harrisburg and nearly 500 feet below the Somerville levels, depths greatly exceeding the amounts which the buried valleys of Ohio are known to reach below the peneplanes. The topography of Kentucky would nevertheless be greatly tempered by drift deposits comparable to those of Ohio, and if the drift of Ohio were removed, the two regions would resemble each other still more closely. An interesting feature in the Kentucky River gorge of the Plateau is the existence of shelves seeming to rise gradually upstream from elevations near 1000 feet; these may be largely structural in origin, but careful field study may show them to be remnants of graded Somerville straths similar to those in Ohio.

Structural Effects in Central Ohio

The preceding comparison between the central parts of Ohio and Kentucky may serve as an introduction to the troublesome problem concerning the effects of structure on erosional surfaces in Ohio. The major evolution of the area in this paper has been attributed to two periods of baseleveling, an interpretation seeming to the author best fitted to the facts, but as the following alternate hypotheses show, it is not impossible to give an explanation of Ohio topography without recourse to peneplanation. Due to the horizontal structure the accordant surfaces which have

been interpreted as evidences of peneplanation may be ascribed to any of the following origins:

(a) The Harrisburg may be a peneplane, the surface called the Somerville, structural.

(b) The Harrisburg may be structural, originating in the cycle which formed the Somerville peneplane.

(c) Both Somerville and Harrisburg may be structural, formed as a result of differential erosion in one cycle.

(d) The Harrisburg and Somerville may both be peneplanes indicating two periods of baseleveling.

Criteria by which these hypotheses may be tested are those by which a peneplane may be distinguished from a structural plain, but they are unfortunately not entirely exclusive. The evidence leading toward a peneplane interpretation will be discussed and contrasted with that for structural control which is mainly the supposed parallelism of structure and plain. So far as known to the writer no one has advocated the latter explanation for the surfaces in Ohio, but the problem can hardly fail to present itself to the geomorphologist.

Several periods of uplift followed by baseleveling are indicated in the Newer Appalachians of Pennsylvania where the beveling of highly folded rocks admits no possibility of structural control. This area is only a few hundred miles from Central Ohio, and the regional diastrophic movements affecting the entire Appalachians were probably effective at least that far west. The only question then is, can the two erosional surfaces described safely be recognized as peneplanes and ascribed to these movements?

The strongest affirmative arguments are found in the Plateau section of this area. There the most conclusive evidence in favor of peneplanation is the well known truth that the Harrisburg surface is not confined to one formation but bevels all indiscriminately. The angle of beveling is not high, for the peneplane slopes southeastward in this area about five feet per mile, while the formations dip eastward between 20 and 30 feet per mile. If the Harrisburg were a structural plain ideally developed it ought to slope eastward not southeastward, and its slope ought

to be at least four times as high. The difference between slope and dip in feet is not great but stated in percentage is impressive, while the difference in direction of slope is also important. The Plateau surface not only bevels all the formations but apparently bevels them at the same altitudes, so that there seems to be no noteworthy differences in elevation between areas of resistant and non-resistant rock. If the Harrisburg were a well developed structural surface it would depart from a simple plain and show a series of westward facing cuestas developed on resistant beds and with gentle backslopes rising about 20 feet per mile. The presence of subsequent and resequent streams and of cuesta-like terraces developed on the front of the Plateau escarpment proves that the dip is strong enough to cause features definitely associated with tilted and not horizontal structure. The slope of the Harrisburg surface is too low to be attributed to a dip that can cause the formation of these features. Were slight cuestas present, they would still not indicate structural control to be all important, for, as shown in the description of the Cumberland Plateau cuesta, such rises on the surface of a peneplane are expectable even with low dips, if some formations are sufficiently resistant. They could also result through later erosion in which case the cuesta tops might be interpreted as the peneplane remnants.

It may appear strange that such cuestas are not common in Central Ohio, but the control of structure in developing features associated with tilted beds is weak in spite of the cases mentioned above. The reason seems assignable to the great homogeneity of resistance of the Plateau rocks; few beds are so much more resistant than their neighbors that they can maintain a dip surface for any length of time after the overlying bed has been removed. In almost all undoubted cases of structural control such as the platforms of the Grand Canyon of the Colorado the formations underlying the terraces are much stronger than those which have been stripped from them. Such necessary variations do not exist in central Ohio and perhaps may be used as an argument against structural control rather than peneplanation. Undoubtedly, if the rocks differed more in resistance, the Plateau here would be a series of low cuestas. In other words, if structural control in

Ohio were strong, it would not have resulted in a surface having the appearance of a peneplane. That the surfaces in Ohio appear to be peneplanes in spite of such structure is the strongest evidence that they are peneplanes.

GEOMORPHIC RESULTS OF GLACIATION

Influences on Relief

5. In spite of the many basic resemblances between the topography of central Kentucky and of central Ohio, glaciation has exerted a powerful geomorphic influence upon the surface of the latter area. Twice at least central Ohio was invaded by the ice, and about five-sixths of the area here discussed was covered by the Illinoian sheet at its greatest extent, while slightly more than two-thirds was later covered by the Wisconsin advance. During each stage the ice seems to have advanced southeastward, and the glacial border, as shown in Fig. 1, extends from north to south across the area not far within its eastern boundary. As a result of the smaller extent of the Wisconsin ice sheet Illinoian drift is exposed over a zone about ten miles wide between the Wisconsin drift on the west and the unglaciated area on the east. The Wisconsin drift boundary extends from north to south along a line about one mile east of the North Fork of the Licking, and west of that line little can be said concerning the topographic effects of earlier glaciation. The characteristic stratigraphy and topography of the Illinoian and Wisconsin drift sheets have been described in many reports among which that of Leverett (*17*) is most useful; the geomorphic effects of these invasions are here to be discussed as of primary interest. Glaciation will be treated as one episode unless the age of the drift is significant in the explanation of the geomorphic history, and those interested in problems of drift stratigraphy are referred to the above mentioned authority or to papers listed in the bibliography. In the following pages two related subjects are considered: (1) the results of glacial erosion and deposition as shown in the present topography, and (2) the modification of preglacial drainage because of the immediate presence of the ice or of glacial deposits.

The Columbus Lowland was entirely covered by the Wisconsin ice, whose moraines (Fig. 1) swinging southward in long festoons between the Bellefontaine hills and the Plateau furnish a strong indication of the greater ease with which the ice advanced over the Lowland with its smaller relief and lesser altitudes. To these topographic differences between Plateau and Lowland the much greater southward advance of the glacier in the latter section has long been attributed. Indeed the situation of the terminal moraine in Ohio strongly suggests that the ice advanced southward through the Lowland until rising above the escarpment it overflowed eastward upon the Plateau for a few miles. Little can be determined concerning the thickness of the ice sheet, but the minimum figure of course exceeded 300 feet, or the ice could not have flowed from the Lowland into the Plateau. The ice overlying the Lowland in any case exceeded in thickness that upon the Plateau by 300 feet. It was therefore a more efficient geomorphic agent and has almost completely hidden the preexisting topography by depositing a sheet of till whose even top is the surface of the Columbus Lowland. This till varies in thickness from zero to over 200 feet; since the entire area was filled to about the same level, it is thinnest above preglacial divides, thickest above preglacial valleys. The present southward flowing streams of the Lowland are frequently bedded in drift at elevations over 150 feet below the surface of the surrounding till plain. In many cases these appear to be flowing across filled preglacial valleys whose depths are not known but indicate a thickness of fill well over 150 feet. At Columbus the records of four wells furnished by the Ohio Geological Survey show depths to bedrock of approximately 148, 100, 104, and 123 feet. Twelve miles northwest of Columbus the drift is said to be over 200 feet thick (*11*), while a comparison of records showing the elevation of bedrock and of the present surface indicates that the greatest thickness of the drift slightly exceeds the preglacial relief, which is placed around 250 feet. Where the surface of the plain is undissected, rock does not outcrop above the till.

The mantling effect of glacial deposits is less important in the Plateau. The preglacial topography is rarely hidden there, for

the relief is not obliterated, although it has been reduced. The chief results of glaciation have been to alter drainage lines but rarely to fill entirely the former valleys. The preglacial relief of the Plateau reached 700 feet, a figure nearly three times as great as that of the Lowland. Débris sufficient to fill to the brim the deep valleys of the Plateau was lacking, especially since the ice there was at least 300 feet less in thickness than in the Lowland. The distribution of drift in the Plateau is very irregular; thicknesses of 300 feet occur in the valleys, but the hilltops are often almost entirely free from transported materials and may show a considerable development of residual soil. Commonly the road cuts passing over the crest of hills show bedrock in various stages of disintegration and covered by a thin veneer of drift which thickens down the slope until the bedrock passes beneath the surface not to be seen again until the next hilltop is reached. Neither the terminal moraine of the Illinoian or Wisconsin ice is a noteworthy feature in the Plateau, and outside of the drainage modifications to be discussed later the chief results of glaciation have been to reduce the total relief about 300 feet. Central Ohio today is a strikingly less rugged country than it was before the coming of the ice.

The figure of 300 feet given as near the maximum thickness of the drift in the Plateau exceeds that given for the Lowland by 50 feet. In the Plateau, however, this thickness of drift is overwhelmingly glacio-fluvial in origin and represents material gathered from a wide area and deposited in favorable localities, while in the Lowland the drift is more largely till seeming to indicate that the ice there could form a thick deposit directly without depending upon streams to collect material scattered thinly over great areas. The greater thickness of drift does not therefore contradict the belief that the glacier was thinner and was handicapped by the topography of the Plateau.

It is difficult to estimate the amount of glacial erosion in this region; in the author's opinion it was small, and the probable correctness of this judgment is supported by the location of all parts of the area within a short distance of the terminus of the ice that passed across it. Landforms due to glacial sculpturing

do not occur, and striae are uncommon. The rarity of the latter is generally not to be attributed so much to their original absence as to destruction by later erosion and to concealment by overlying deposits. Striae rarely if ever are found within the Plateau and in general seem to be most rare in areas of shale and shaly sandstone. This is attributed largely to their removal by later weathering, but the deposits of residual soil passing by gradation into bedrock are of such thickness and of such common occurrence in the Plateau that the author assigns the absence of striae there in considerable degree to the weakness of glacial erosion. The zone of disintegrated rock and soil is sometimes 10 to 15 feet thick; too great to be considered Post-Wisconsin in origin, and it seems probable that the ice advancing over the Plateau did not remove enough weathered material to expose surfaces sufficiently sound to take striae. Striae are more common on the limestone and are occasionally exposed by stripping preparatory to quarrying operations. In such places the surface of the rock may be well polished and even slightly grooved, but in flat lying beds this does not necessarily indicate deep erosion. It is true that the contact between the drift and limestone is usually sharp seeming to indicate the removal of all preglacial weathering products, but this does not entail the removal of much fresh rock, since the contact between fresh limestone and its weathering products is clear-cut in any case. Hubbard[5] mentions a number of cases where the clay and rubble collected in the gaping throat of a sinkhole had not been removed. Such unconsolidated débris would scarcely remain had glacial erosion been deep.

The till of central Ohio, nevertheless, is composed predominantly of materials of rather local origin. In the Plateau the common occurrence of a thick layer of disintegrating rock and soil seems to indicate that the glacier gained much of this débris from materials already loosened by weathering. These residual soils are located on hilltops where erosion should have been greatest, the depth of weathering precludes the possibility that it is post-glacial, and one must conclude that the ice in the Plateau

[5] Hubbard, *cf.* Bibliography (*11*), pp. 62–65.

was rarely an erosive agent strong enough to reach fresh rock. In the Lowland residual soils in general have been stripped away, the limestone surfaces freshened, and as indicated in places by the calcareous character of the till a few feet of fresh rock may have been ground away. In general, however, the important erosive work in both sections was largely the removal of already loosened material, and there are no indications of very successful activity in attacking fresh rock.

About twenty striae localities have been recorded from the limestone areas of Central Ohio. In general they are too rare to be found without special search, and the writer discovered only one unrecorded locality. This hitherto unlisted occurrence is in a small limestone quarry about one mile southwest of Warrensburg. The striae extend south twenty degrees east, a trend which appears to be near the average. The general direction of ice movement was probably not far from south 15 degrees east, although two or three cases showing southwestward movement are known. In view of this southeasterly trend it is noteworthy that the ice of the Scioto lobe is believed to have come from the Labrador center flowing southwestwardly along the Lake Erie trough until the Plateau cuesta turned southward. There the glacier escaped southward moving readily into and down the Columbus Lowland and spilling over onto the Plateau. In the absence of striae the trend of ice movement in the Plateau is problematical. Two striae records at Sunbury just west of the escarpment trend south 45 degrees east, and the situation of the terminal moraine and of drainage lines later to be mentioned indicates a very large easterly component of flow.

The surface of the Columbus Lowland is described as a till plain (Plate VI) sloping southward about seven feet per mile. Many well records and the occurrence of drift filled preglacial valleys indicate that the even surface of the till plain may lead to an incorrect conception of the regularity of the bedrock surface which it conceals. The relief of this surface, as has been stated, approached 250 feet and was only slightly less than the maximum thickness of the drift sheet which almost entirely covers it. No rock outcrops stand higher than the general level

of the till plain on major stream divides, but many observations indicate that the drift cover is often very thin where preglacial valleys are absent. Bedrock may be exposed in such areas through quarrying operations involving the removal of only two or three feet of till overburden or by the channels of streams often cut less than five feet below the surface of the plain. Such outcrops are usually not much weathered, and the contacts between till and rock are often horizontal over considerable areas. These occurrences seem to indicate that large remnants of the Somerville peneplane were still flat and undissected before glaciation. Numerous well records indicate that the southward slope of the till plain is not due to decreased deposition toward the south but is dependent upon the slope of the preglacial surface. These facts indicate that the present surface of the till plain closely parallels in slope that of the Somerville, although its dissection is much less.

All the major streams of the Columbus Lowland are consequent upon the southward slope of the till plain and presumably occupied their present courses as rapidly as the ice retreated. The only interruptions to the southward slope are furnished by two recessional moraines (Fig. 1), known as the Powell and the Broadway moraines (*17*). Although these moraines extend directly across the streams and may reach heights of 60 feet, they seem to have had little or no effect in deflecting the drainage, for the major streams pass into and through them without bending to right or left. Both moraines are convex southward: the Powell moraine can be traced on the Dublin, Westerville, and Marengo quadrangles as a ridge of irregular width passing through New California, Powell, Sunbury, and Marengo; the Broadway Moraine is apparent on the Delaware and Marengo Quadrangles passing through Ostrander, Leonardsburg, West Liberty, and South Woodbury. Within this distance each changes its trend from east to north as it approaches the Plateau escarpment, and each has for a number of miles governed the course of a considerable stream. From Sunbury north the Powell moraine is against and parallel to the Plateau escarpment; it reaches elevations of 1150 feet not far below that of the adjacent Plateau, and

its western slope may easily be mistaken for the escarpment. From near Marengo south to Sunbury Big Walnut Creek flows in the consequent depression between the escarpment and the front of the moraine. It follows the moraine southwestward from Sunbury as far as Galena where the stream turns to the south and flows along the foot of the escarpment. In a like manner Alum Creek follows the front of the Broadway moraine from Fulton to Kilbourne, and from West Liberty to Fulton is pressed against the front of the lowest terrace of the escarpment.

The manner in which the streams pass through the moraines without deviation indicates that at their points of passage transverse depressions must have existed from the very time that the ice was present. Some ponding may have occurred behind the moraines until the water rose and escaped through the low points, or the melt water may have cut down these depressions so rapidly that ponding was unnecessary. The lower elevations in the moraines are due either to decreased deposition at these points or to depressions in the bedrock surface which were not completely hidden by deposition. The latter seems more likely, for if the depressions in the moraines were due to uneven deposition their location should show no relationship to the courses of the streams north and south of them. Streams flowing from the north would reach the moraine, turn east or west to find a low passage, and then on the south possibly turn to east or west again to find a consequent depression in the till plain. It could hardly be expected that the most favorable passage through the moraines would always be located fortuitously on the consequent paths of the streams on the till plains. The absence of changes in direction at the moraine indicates an underlying cause.

The almost rectilinear courses of the streams north of Columbus are too remarkable to be due to southward consequence upon the slope of the till plain alone. Longitudinal trenches of slight depth seem to be required, and these are presumably due to preglacial depressions which have not been entirely obliterated by débris. Such depressions would cause the low points in the moraines to be in line with the low points in the till plain, and the

streams would not change their direction in passing through the moraines. Westgate (*30*) has noted that the Scioto and Olentangy Rivers, and to a lesser extent Alum Creek, in Delaware County occupy steep walled inner valleys in much broader shallow rock trenches containing varying thicknesses of Wisconsin till. These features may be seen on the Westerville and Dublin Quadrangles, where the topographic break between the gentle outer valley and the steep inner valley is marked. Probably due to the greater resistance of the limestone on which it is located, the inner valley of the Scioto, which has been dammed to form the Columbus reservoirs, is much narrower than that of the Olentangy and the Alum, located on the Ohio shale. In a number of localities, notably between Marble Cliff and Slate Run on the Scioto, well developed rock terraces are found; Westgate has interpreted these as remnants of the valley floor of the preglacial outer valleys brought to light by removal of the drift veneer, while Hubbard (*10*) assigns most of them to post-glacial downcutting by the present streams. According to Westgate the present streams are consequent on the partly filled trenches of preglacial subsequents, an interpretation which fits well with the manner in which the streams pass through the moraines, and with the mature outer slopes and the youthful inner valleys of such streams as the Scioto.

At Columbus the Olentangy joins the Scioto River which within the limits of this area does not again flow on bedrock. Alum and Blacklick Creeks flow into Big Walnut Creek five miles southeast of Columbus, and the latter stream enters the Scioto ten miles south of the city. A few miles south of the boundary of the area Darby and Little Walnut Creeks enter the Scioto River. The absence of rock in the Scioto indicates that it is following a deep preglacial valley, while the junction of three streams at one place may be due to chance but is more likely to be caused by a slight consequent depression such as is expectable above a nearly filled preglacial valley. South of Columbus the streams thus appear to converge rapidly upon a consequent depression which is probably formed by the buried Newark Valley entering the Lowland at Canal Winchester.

Glacial Modifications of Drainage

Changes of drainage due to damming of preglacial channels by the ice front or by glacial deposits are so numerous in the Plateau of central Ohio that the area has become classic ground for such studies chiefly through the work of Tight and his students. The streams flowing toward the ice were naturally the ones to be most affected; since the ice entered the area from the northwest, and the front extended across it from north to south, without exception the larger streams flowing in westerly directions were dammed. The path of escape for the ponded waters was away from the ice front toward the south and east, and as a result the narrow postglacial gorges almost universally extend in that direction. Evidences of drainage changes in this area include well records showing reversal of bedrock slope in deep drift-filled valleys, broad valleys unoccupied by streams of corresponding size, rock-walled gorges, and broad shallow depressions marking the location of large valleys now drift-filled.

Since the modifications have so generally been made at the expense of westward and southwestward flowing streams in favor of those flowing southeastward, warping with movement relatively downward toward the southeast has been brought forward as an alternative hypothesis by Carney (*4*, *3*, *20*, *19*) and some of his students. These workers regard the drainage changes as true cases of stream capture by southeastward flowing streams, whose vigor has been increased by the tilting in that direction. Because of the width of the new valleys which in general approach submaturity rather than youth, they argue for preglacial diversion, since they believe streams diverted during the glacial invasion would not yet have had sufficient time to cut more than an extremely youthful gorge.

Certain factors favoring piracy by southeastward flowing streams are present. The Harrisburg surface slopes southeastward about five feet per mile, a slope which may be due to a differential uplift, whose presence was inferred by Carney. Streams flowing in that direction after uplift would have their gradients steepened by five feet, while those flowing toward the

northwest would have theirs lessened by that amount. This would make a difference of ten feet per mile in favor of the southeastward flowing streams, an amount seemingly large enough to have caused considerable readjustment of divides. On the other hand most of the abandoned valleys are those of streams flowing southwestward parallel to the axis of uplift; warping would not greatly change their gradients, and that factor in favor of the supposed diverting streams would therefore be in general nearer five feet per mile. In addition, it has been stated that the western tributaries of many southward flowing streams are longer than the eastern. The resequent streams flowing in the direction of the low dip seem to have been favored to the disadvantage of the obsequents flowing against the dip, and from this it might be gathered that the southeastward flowing streams occupying in general the position of resequents had captured those flowing southwestward in this region. Analysis shows the improbability of this. Resequent streams on the dip slopes of such a series of sediments as occur in central Ohio do not grow by headward erosion and thus lack the first essential for successful piracy. They grow mouthward as the slope is lengthened down the dip by continued stripping, and their headwaters rather than being extended are being restricted by headward erosion of the obsequents with their markedly steeper gradients. The Kaaterskill (7) case in eastern New York is a classic example of the manner in which obsequents grow at the expense of resequents. Although the conditions in Central Ohio are much less favorable for such piracies than in the Catskill Mountains, it seems probable that here also the dip of the strata hinders rather than facilitates capture by streams flowing down the dip. The importance of this tendency cannot be determined, but it seems probable that it balances or exceeds any advantage afforded to the southeastward flowing streams by warping of only a few feet per mile.

Causes for capture thus seem to be lacking or very weak, while in any case it seems unnecessary to appeal to capture in the known presence of an adequate cause of modification without capture. Deposits of glacial origin are found in close conjunction with every case of drainage change in this area and leave no doubt

but that all are due to glacial and not diastrophic causes. The submaturity of some of the new valleys is not an important obstacle to this interpretation, for many of these valleys were channels of escape for floods of meltwater heavily armed with erosive tools, and under such conditions they would develop rapidly and now appear over-mature for the shrunken streams occupying them. In the absence of definite criteria it is unsafe to assert that certain streams cannot have accomplished a certain amount of work in a certain poorly determined length of time. Furthermore, some of these diversions are undoubtedly due to pre-Wisconsin glaciations which, with the constant tendency to lengthen Pleistocene time, seems to indicate that the estimate of the number of years during which the new valleys have been occupied must be greatly enlarged.

Drainage modifications undoubtedly occurred in the Columbus Lowland as well as in the Plateau, but the evidences are in general lost beneath the surface of the till plain. It was a case of extinction rather than dismemberment of the former drainage, and although well records point to many buried valleys little can be said concerning them. In a succeeding number of this journal the discussion is to be concluded with a consideration of two important rivers of the Plateau, the old Newark and the old Vernon Rivers and their tributaries, and of the postglacial history of Central Ohio.

BIBLIOGRAPHY

(*1*) Campbell, M. L.; "Geographic Development of Northern Pennsylvania and Southern New York," Geol. Soc. Am., Bull. 14, 277–296 (1903).

(*2*) Carney, Frank; "Glacial Dams at Hanover, Ohio," Denison University Bull., Jour. Sci. Lab., 13, 139–153 (1907).

(*3*) Carney, Frank; "Valley Dependencies of the Scioto Illinoian Lobe in Licking County, Ohio," Denison University Bull., Jour. Sci. Lab., 12, 131–138 (1907).

(*4*) Carney, Frank; "A Stratigraphical Study of Mary Ann Township, Licking County, Ohio," Denison University Bull., Jour. Sci. Lab., 14, 127–156 (1909).

(*5*) Clark, W. B.; "Drainage Modifications in Knox, Licking, and Coshocton Counties, Ohio," Denison University Bull., Jour. Sci. Lab., 12, 1–16, (1902).

(*6*) Columbus Folio, U. S. Geol. Surv., Folio 197, 11 (1915).

(7) DARTON, N. H.; "Examples of Stream-Robbing in the Catskill Mts.," Geol. Soc. Am., Bull. 7, 505–507 (1896).

(8) DAVIS, H. J.; "Modification of the Jonathan Creek Drainage Basin," Denison University Bull., Jour. Sci. Lab., 11, 166–173, (1899).

(9) FENNEMAN, N. M.; "Physiographic Division of the United States," Annals Assoc. Am. Geog., 18, 264–353, (1928).

(10) HUBBARD, G. D.; "Rock Terraces Along Streams Near Columbus, Ohio," Ohio Naturalist, 4, 397–403, (1908).

(11) HUBBARD, G. D.; "Columbus Quadrangle," Geological Survey of Ohio, 4th Ser. Bull. 14; 15 and Plate 15 (1911).

(12) HYDE, J. E.; "Geology of Camp Sherman Quadrangle," Geol. Surv. Ohio, 4th Series Bull. 23, 164–165 (1921).

(13) JOHNSON, D. W.; "A Theory of Appalachian Geomorphic Evolution," Jour. of Geol. 39, 497–508 (1931).

(14) JOHNSON, D. W.; "Stream Sculpture on the Atlantic Slope," 142 pp., Columbia Univ. Press, N. Y., (1931).

(15) Kittanning Folio, U. S. Geol. Surv. Folio 115, 3 (1904).

(16) LAMBORN, R. E.; "Geology of Jefferson County," Geol. Surv. of Ohio, 4th Series, Bull. 35, 13 (1930).

(17) LEVERETT, FRANK; "Glacial Formations and Drainage Features of the Erie and Ohio Basins," (*cf.* Plate II). U. S. Geol. Surv., Mon. 41, 802 pp. (1902).

(18) LEVERETT, FRANK; "Changes in Drainage in Southern Ohio," Denison University Bull., Jour. Sci. Lab., 9, 18–29 (1897).

(19) MATHER, K. F.; "The Age of Licking Narrows at Black Hand, Ohio," Denison University Bull., Jour. Sci. Lab., 14, 175–186 (1909).

(20) SCHEFFEL, E. R.; "Significance of Drainage Changes Near Granville, Ohio," Denison University Bull., Jour. Sci. Lab., 14, 157–174 (1909).

(21) SHARP, H. S.; "The Physical History of the Connecticut Shoreline," Conn. Geol. Surv., Bull. 46, 34–36 (1929).

(22) STAUFFER, C. R., HUBBARD, G. D., AND BOWNOCKER, F. A.; "Geology of the Columbus Quadrangle," Geol. Surv. of Ohio, 4th Series, Bull.14, Plate 15 (1911).

(23) STOUT, W., AND SCHAAF, D.; "Minford Silts of Southern Ohio," Geol. Soc. Am. Bull. 42, 663–672 (1931).

(24) TIGHT, W. G.; "Contribution to the Knowledge of Preglacial Drainage in Ohio," Denison University Bull., Jour. Sci. Lab., 8, 35–63 (1894).

(25) TIGHT, W. G.; "A Preglacial Valley in Fairfield Co.," Denison University Bull., Jour. Sci. Lab., 9, 33–37 (1895).

(26) TIGHT, W. G.; "Drainage Modifications of Southeastern Ohio," U. S. Geol. Surv. Prof. Paper 13; 55 and 93, Plate I (1903).

(27) VER STEEG, KARL; "Some Features of Appalachian Peneplanes," Pan-American Geologist, 53, 359–364; 54, 17–28 (1930).

(28) VER STEEG, KARL; "Erosion Surfaces of the Appalachians," Pan-American Geologist, 56, 267–284 (1931).

(29) WARD, FREEMAN; "The Rôle of Solution in Peneplanation," Jour. of Geol., 38, 262–270 (1930).

(*30*) WESTGATE, L. G.; "Delaware County," Geological Survey of Ohio, 4th Ser. Bull. 30, 100–102 (1926).

(*31*) WHITE, G. W.; "Glaciation of Northwestern Holmes County, Ohio," Ohio Jour. Sci. 31, 429–452 (1931).

(*32*) WRIGHT, F. J.; "The Older Appalachians of the South," Denison University Bull., Jour. Sci. Lab., 26, 143–250 (1931).

PLATE I. SKYLINE OF THE DISSECTED APPALACHIAN PLATEAU SOUTHWEST OF GRANVILLE, OHIO

PLATE II. SKYLINE OF THE DISSECTED APPALACHIAN PLATEAU NORTH OF GRANVILLE, OHIO

PLATE III. WESTERN ESCARPMENT OF THE APPALACHIAN PLATEAU FIVE MILES WEST OF IRVINE, KENTUCKY

The Plateau level is correlated with the Harrisburg peneplane, the intermediate surface is the Somerville, while post-Somerville erosion is seen in the valley in the foreground. Compare this marked plateau escarpment with that shown in Plates IV and V.

PLATE IV. LOOKING NORTHEASTWARD TOWARD REYNOLDSBURG FROM THE TOP OF AN ESKER SIX MILES EAST OF COLUMBUS

The gentle slope on which the distant buildings are clustered is the lowest cuesta of the plateau escarpment and ascends about 100 feet in about one mile.

PLATE V. LOOKING NORTHEAST AT THE PARTLY WOODED HIGHEST CUESTA OF THE PLATEAU ESCARPMENT FROM A POINT ON THE PENNSYLVANIA RAILROAD TWO MILES WEST OF PATASKALA

Note the gentle eastward slope of the intermediate terrace.

PLATE VI. UNDISSECTED SURFACE OF THE COLUMBUS LOWLAND LOOKING SOUTHEAST TOWARD PORT COLUMBUS

The slightly higher skyline is the lowest cuesta of the plateau escarpment just east of Big Walnut Creek.

VOLUME 17

Articles 1–4, pp. 1–201; March, 1912 ..... $1.50

A geographic interpretation of Cincinnati, Ohio; Edith M. Southall. 16 pp.
Strophomena and other fossils from Cincinnatian and Mohawkian horizons, chiefly in Ohio, Indiana, Kentucky; Aug. F. Foerste. 158 pp., 18 plates.
Population centers and density of population; F. Carney. 15 pp.
The climate of Ohio; F. Carney. 9 pp.

Articles 5–7, pp. 203–246; March, 1913 ..... $0.40

The twenty-fifth anniversary of the founding of the Denison Scientific Association; 2 pp.
The foundation of culture; C. Judson Herrick. 14 pp.
Drainage changes in the Moots Run area, Licking County, Ohio; Harmon A. Nixon and Dexter J. Tight. 11 pp., 1 fig.
Some pre-glacial lake shorelines of the Bellevue Quadrangle, Ohio; F. Carney. 16 pp., 3 figs.

Articles 8–10, pp. 247–373; March, 1914 ..... $1.00

Lorraine faunas of New York and Quebec; Aug. F. Foerste. 93 pp., 5 plates.
A comparative study of circular and rectangular Inhoff tanks; Theodore Sedgwick Johnson. 26 pp.
Geographic factors in the establishing of the Ohio-Michigan boundary line; Constance Grace Eirich. 7 pp.

Articles 11–14; pp. 375–487; September, 1914 ..... $1.00

A method of subdividing the interior of a simply closed rectifiable curve with an application to Cauchy's theorem. F. B. Wiley and G. A. Bliss. 14 pp., 3 figs.
The influence of glaciation on agriculture in Ohio; Edgar W. Owen. 4 pp., 1 fig.
The Locust Grove Esker, Ohio; James D. Thompson, Jr. 4 pp., 1 fig.
Notes on Agelacrinidae and Lepadocystinae, with descriptions of Thresherodiscus and Brockocystis; Aug. F. Foerste. 88 pp., 6 plates.

VOLUME 18

Articles 1–3, pp. 1–284; December, 1915 ..... $1.75

Proceedings of the inauguration of President Chamberlain; 54 pp.
Denison University presidents; William Hannibal Johnson. 5 pp.
The fauna of the Morrow Group of Arkansas and Oklahoma; Kirtley F. Mather. 226 pp., 2 figs., 16 plates.

Articles 4–7, pp. 285–378; December, 1916 ..... $1.10

Notes on Cincinnatian fossil types; Aug. F. Foerste. 71 pp., 7 plates.
The shorelines of glacial lakes Lundy, Wayne, and Arkona, of the Oberlin Quadrangle, Ohio; Frank Carney. 6 pp. 1 fig.
The progress of Geology during the period 1891–1915; Frank Carney. 8 pp., 4 figs.
The abandoned shorelines of the Ashtabula Quadrangle, Ohio; Frank Carney. 24 pp., 4 figs.

VOLUME 19

Articles 1–4, pp. 1–64; April, 1919 ..... $0.75

Echinodermata of the Brassfield (Silurian) formation of Ohio; Aug. F. Foerste. 30 pp., 7 plates.
America's advance in potash production; W. C. Ebaugh. 14 pp., 2 figs.
The use of outline charts in teaching vertebrate paleontology; Maurice G. Mehl. 8 pp., 1 fig., 4 plates.
Some factors in the geographic distribution of petroleum; Maurice G. Mehl. 9 pp., 2 plates.

Articles 5–8, pp. 65–146; September, 1919 ..... $0.75

Notes on Isotelus, Achrolichas, Calymene and Encrinurus; Aug. F. Foerste. 18 pp., 6 plates.
Some suggested experiments for the graphic recording of speech vibrations; Robert James Kellogg. 14 pp., 6 figs.
The manipulation of the telescopic alidade in geologic mapping; Kirtley F. Mather. 46 pp., 13 figs.
The importance of drainage area in estimating the possibilities of petroleum production from an anticlinal structure; Kirtley F. Mather and Maurice G. Mehl. 4 pp., 2 plates.

Articles 9–12, pp. 147–224; May, 1920 ..... $0.75

Psychological factors in vocational guidance; Thomas A. Lewis. 10 pp.
The use of models in the interpretation of data for determining the structure of bedded rocks; Maurice G. Mehl. 12 pp., 6 figs., 2 plates.
Some suggestions for indicating drilling operations; Maurice G. Mehl. 6 pp., 3 figs.
The Kimmswick and Plattin limestones of Northeastern Missouri; Aug. F. Foerste. 50 pp., 3 plates.

Articles 13–16, pp. 225–329; September, 1921 ..... $0.75

Education for scholarship; William E. Castle. 9 pp.
The cytology of the sea-side earwig, Anisolabis maritima Bon., part 1; Sidney I. Kornhauser. 13 pp., 3 plates.
Notes on Arctic Ordovician and Silurian cephalopods; Aug. F. Foerste. 60 pp., 9 plates.
Revolution vs. evolution: the paleontologist renders his verdict; Kirtley F. Mather. 18 pp.

VOLUME 20

Articles 1–3, pp. 1–36; November, 1922 ..... $0.50

A review of the biology of sex-determination; Sidney I. Kornhauser. 21 pp., 8 figs.
The Meander patterns of Rios Securé and Mamoré, Eastern Bolivia; Kirtley F. Mather. 7 pp., 2 figs.
Primitive musical instruments of the Denison Collection; Karl H. Eschman. 10 pp., 3 plates.

Articles 4–8, pp. 37–186; June, 1923 ..... $0.75

Notes on Medinan, Niagaran, and Chester fossils; Aug. F. Foerste. 84 pages, 13 plates.
The egg and larvae of Hesperia juba Bdv.; A. W. Lindsey. 7 pp., 1 plate.
The occultation of Venus by the Moon on January 13, 1923; P. Biefeld. 4 pp., 1 plate.
A botanical survey of the campus of Denison University; Dwight Munson Moore. 23 pp., 7 figs. 3 plates.
The underground migration of oil and gas; Kirtley F. Mather. 31 pp., 1 fig.

Articles 9–13, pp. 187–383; December, 1924 ..... $1.25

Trichoptilus pygmaeus Wism. and the Neuration of the Family Pterophoridae,; A. W. Lindsey. 6 pp., 6 plates.
Notes on American Paleozic Cephalopods; Aug. F. Foerste. 76 pp., 22 plates.
A Report on the Theory of Relati vity (Einstein Theory); Paul Biefeld. 20 pp.
Some Problems of Taxonomy; A. W. Lindsey. 18 pp., 1 plate.
Notes on the Geology of Giles County, Virginia; George D. Hubbard and Carey G. Cronels. 72 pp., 1 plate.

VOLUME 21

Articles 1–3, pp. 1–116; March, 1925 ..... $1.25

Notes on Cephalopod Genera; Chiefly Coiled Silurian Forms; Aug. F. Foerste. 70 pp., 23 plates.
The Cornell University Entomological Expedition to South America of 1919–1920. Scientific Results No. II. Hesperiodea; A. W. Lindsey. 44 pp., 6 plates.
Photographic Record of the Partial Solar Eclipse of January 24, 1925; Paul Biefeld. 2 pp., 1 plate.

Article 4, pp. 117–283; September, 1925 ..... $1.50

The Agricultural Geography of the Salt Lake Oasis; Charles Langdon White. 167 pp., 34 figs.

Articles 5–7, pp. 285–404; September, 1926 ..... $1.25

Actinosiphonate, Trochoceroid and other Cephalopods; Aug. F. Foerste. 100 pp., 22 plates.
Brachiopods from the St. Clair Limestone, Arkansas; Norman L. Thomas. 18 pp., 1 plate.
Notes on the Preparation of Hydrogen Sulfide and Hydrogen Iodide; W. C. Ebaugh. 2 pp

VOLUME 22

Articles 1–4, pp. 1–135, March, 1927 ..... $1.50

Ordovician and Silurian Cephalopods of the Hudson Bay Area; Aug. F. Foerste and T. E. Savage. 108 pp., 24 plates, 1 map.
Notes on Phylogeny in Erynnis Schr. (Thanaos Auct.); A. W. Lindsey. 7 pp., 1 fig.
The Blue Ridge of Southern Virginia and Western North Carolina; Frank J. Wright. 17 pp., 4 figs., 2 plates.
Gravels of the Blue Ridge; Frank J. Wright. 3 pp., 1 fig.

Articles 5–9, pp. 137–193, October, 1927 ..... $1.00

Science and Religion (Address); Robert A. Millikan. 10 pp.
Forty Years of Scientific Thought Concerning the Origin of Life (Address); Kirtley F. Mather. 11 pp.
Darwin as a Pioneer in Evolution (Address); George A. Dorsey. 14 pp.
Science and Living (Address); C. Judson Herrick. 9 pp.
Founding of the Denison Scientific Association (Address); Alfred D. Cole. 6 pp.

VOLUME 23

Articles 1–2, pp. 1–126, January, 1928 ..... $1.50

American Arctic and Related Cephalopods; Aug. F. Foerste. 110 pp., 29 plates.
Apatodonosaurus, a New Genus of Ichthyosaurs from the Jurassic of Wyoming; M. G. Mehl. 16 pp., 2 figs., 6 plates.

Articles 3–5, pp. 127–230, July, 1928 ..... $1.50

Some Brachiopods from the St. Clair Limestone, Arkansas. Norman L. Thomas. 13 pp., 1 plate.
The Phytosauria of the Wyoming Triassic. M. G. Mehl. 32 pp., 9 figs., 3 plates.
A Restudy of some of the Ordovician and Silurian Cephalopods described by Hall. Aug. F. Foerste. 58 pp., 8 plates.

Articles 6–8, pp. 231–355, December, 1928 ..... $1.50

Hesperioidea from the Kartabo District of British Guiana; A. W. Lindsey. 5 pp., 5 figs.
A Restudy of American Orthoconic Silurian Cephalopods; Aug. F. Foerste. 85 pp., 28 plates.
The Erosional History of the Blue Ridge; Frank J. Wright. 24 pp., 10 plates.

VOLUME 24

Articles 1–5, pp. 1–113, April, 1929 ..... $1.50

Hypoparia and Opisthoparia from the St. Clair Limestone, Arkansas; Norman L. Thomas. 26 pp., 1 plate
Ordovician and Silurian of American Arctic and Subarctic Regions; Aug. F. Foerste. 54 pp., 2 plates.
Location Factors in the Iron and Steel Industry of Cleveland, Ohio; Charles Langdon White. 16 pp., 4 figs., 1 plate.
A Photographic Record of the Total Eclipse of the Moon; Paul Biefeld. 2 pp., 1 plate.
Basslerina, a New Holliniform Ostracode Genus, with Description of New Pennsylvanian Species from Texas and Oklahoma; Raymond C. Moore. 15 pp., 3 plates.

Articles 6–9, pp. 115–264, August, 1929 ..... $1.50

Some Proparia from the St. Clair Limestone, Arkansas; Norman L. Thomas. 14 pp., 2 plates.
Cephalopods of the Red River Formation of Southern Manitoba; Aug. F. Foerste. 107 pp., 29 plates.
A Large Fish Spine from the Pennsylvanian of North Central Texas; Raymond C. Moore. 7 pp., 1 plate.
Location Factors in the Iron and Steel Industry of the Buffalo District, New York; Charles Langdon White. 20 pp., 6 figs.

Articles 10–13, pp. 265–427, December, 1929 ..... $1.50

Three Studies of Cephalopods; Aug. F. Foerste. 117 pp., 23 plates.
A New Genus of Mosasaurs from Mexico, and Notes on the Pelvic Girdle of Platecarpus; M. G. Mehl. 18 pp., 5 figs., 4 plates.
Stream Piracy near Asheville, N. C.; Frank J. Wright. 6 pp., 1 fig., 1 plate.
Motor Vehicle Transportation Cost and its Relation to Highway Finance; Bruce D. Greenshields. 6 pp., 1 fig.

VOLUME 25

Articles 1–3, pp. 1–164; April, 1930 ..... $1.50

Port Byron and Other Silurian Cephalopods; Aug. F. Foerste. 124 pp., 2 figs., 25 plates.
The Iron and Steel Industry of Youngstown, Ohio; Charles Langdon White. 22 pp., 7 figs.
New Species of Bryozoans from the Pennsylvanian of Texas; Raymond C. Moore. 17 pp., 1 plate.

Articles 4–5, pp. 165–200, August, 1930 ..... $1.00

Visual Localization in the Horizontal Plane; Winford L. Sharp. 9 pp.
Petroleum Products for Internal Combustion Engines; Milton Finley. 26 pp., 3 figs.

Articles 6–7, pp. 201–299, December, 1930 ..... $1.00

The Actinoceroids of East-Central North America; Aug. F. Foerste and Curt Teichert. 96 pp., 33 plates.
The Presence of Nybyoceras in South Manchuria; Riuji Endo. 3 pp., 1 plate.

VOLUME 26

Article 1, pp. 1–142; April, 1931 ..... $1.50

The Hesperioidea of North America; A. W. Lindsey, E. L. Bell and R. C. Williams, Jr. 142 pp., 33 plates.

Article 2, pp. 143–250; December, 1931 ..... $1.50

The Older Appalachians of the South; Frank J. Wright. 108 pp., 38 plates.

VOLUME 27

Article 1, pp. 1–46; June, 1932 ..... $1.50

The Geomorphic Development of Central Ohio (Part I); Henry S. Sharp. 46 pp., 1 fig., 6 plates.